# Invasive and Concomitant Noninvasive Intraoperative Blood Pressure Monitoring

## *Observed Differences in Measurements and Associated Therapeutic Interventions*

David B. Wax, M.D.,* Hung-Mo Lin, Ph.D.,* Andrew B. Leibowitz, M.D.†


## ABSTRACT

**Background:** Noninvasive (NIBP) and intraarterial (ABP) blood pressure monitoring are used under different circumstances and may yield different values. The authors endeavored to characterize these differences and hypothesized that there could be differences in interventions associated with the use of ABP alone ([ABP]) *versus* ABP in combination with NIBP ([ABP+NIBP]).

**Methods:** Simultaneous measurements of ABP and NIBP made during noncardiac cases were extracted from electronic anesthesia records; the differences were subjected to regression analysis. Records of blood products, vasopressors, and antihypertensives administered were also extracted, and associations between the use of these therapies and monitoring strategy ([ABP] *vs.* [ABP+NIBP]) were tested using univariate, multivariate, and propensity score matched analyses.

**Results:** Among 24,225 cases, 63% and 37% used [ABP+NIBP] and [ABP], respectively. Systolic NIBP was likely to be higher than ABP when ABP was less than 111 mmHg and lower than ABP otherwise. Among patients with hypotension, transfusion occurred in 27% *versus* 43% of patients in the [ABP+NIBP] *versus* [ABP] group, respectively (odds ratio = 0.4; 95% CI 0.35–0.46), and 7% *versus* 18% of patients in the [ABP+NIBP] *versus* [ABP] group received vasopressor infusions, respectively ($P < 0.01$). Among hypertensive patients, 12% *versus* 44% of those in the [ABP+NIBP] *versus* [ABP] group received antihypertensive agents, respectively ($P < 0.01$).

**Conclusions:** NIBP was generally higher than ABP during periods of hypotension and lower than ABP during periods of hypertension. The use of NIBP measurements to supplement ABP measurements was associated with decreased use of blood transfusions, vasopressor infusions, and antihypertensive medications compared with the use of ABP alone.


### What We Already Know about This Topic

- Noninvasive (NIBP) and intraarterial (ABP) blood pressure monitoring are used under different circumstances and may yield different values.

### What This Article Tells Us That Is New

- In a clinical review, NIBP tended to be higher than radial ABP during periods of hypotension and lower than ABP during periods of hypertension. Concomitant use of NIBP with ABP was associated with decreased use of transfusions, vasopressors, and antihypertensives compared with use of ABP alone.

NONINVASIVE blood pressure measurement (NIBP) is accepted as the standard monitoring modality in most clinical settings.[1] However, when there is a need for accurate, reliable, beat-to-beat monitoring of blood pressure, an intraarterial catheter (ABP) is considered the standard.[2] The perceived superiority of such invasive monitoring helps justify the placement of intraarterial catheters and leads some practitioners to forego NIBP monitoring in patients once such a catheter is placed.

Studies comparing ABP and NIBP have been based on small samples of critically ill or cardiac surgery patients and may not be applicable to the large numbers of patients undergoing anesthesia for noncardiac surgery. The advent of anesthesia information management systems (AIMS) has made it possible to compare NIBP and ABP obtained simultaneously using a much larger sample size. Therefore, we used our AIMS data to better characterize the differences between simultaneous ABP and NIBP measurements in actual clinical use. We further hypothesized that there might be significant differences in therapeutic interventions depending on whether ABP was used alone ([ABP]) or in combination with NIBP ([ABP+NIBP]).

* Associate Professor, Department of Anesthesiology, † Professor, Departments of Anesthesiology and Surgery, Mount Sinai School of Medicine, New York, New York.

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Address correspondence to Dr. Wax: Department of Anesthesiology, Mount Sinai School of Medicine, 1 Gustave L. Levy Place, Box 1010, New York, New York 10029. david.wax@mssm.edu. Information on purchasing reprints may be found at www.anesthesiology.org or on the masthead page at the beginning of this issue. ANESTHESIOLOGY's articles are made freely accessible to all readers, for personal use only, 6 months from the cover date of the issue.

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## Materials and Methods

With institutional review board approval and waiver of informed consent (Mount Sinai School of Medicine, Program for the Protection of Human Subjects, New York, New York), all anesthesia case records from 2003 to 2009 in our AIMS (CompuRecord; Philips, Andover, MA) were screened to identify those in which a radial artery catheter was used for continuous blood pressure monitoring for more than 30 min during surgery (excluding cases using cardiopulmonary bypass) in adult patients at our large urban academic hospital. For all such cases, the intraarterial systolic, mean, and diastolic blood pressure measurements (recorded automatically by our AIMS for every 15-s epoch) were extracted. For each of these ABP measurements, records of any intermittent NIBP measurements made simultaneously (typically at a brachial artery site) were also extracted. During the study period, measurements had been made using M-PRESTIN or M-NETPR modules (GE-Healthcare/Datex-Ohmeda, Wauwatosa, WI) in our anesthesia machines with compatible pressure transducers and oscillometric cuffs. Records of erythrocyte transfusions, continuous vasopressor or inotrope infusions, and antihypertensive drug administrations (none of which were guided by a formal protocol at our institution during the study period) were extracted from case records, as was relevant patient and procedure information. Hospital administrative and laboratory records were obtained regarding adverse outcomes (*i.e.*, in-hospital mortality or abnormal troponin within 30 postoperative days).

### Statistical Analysis

The difference between NIBP and ABP measurements was calculated for each simultaneous data pair, and the average and SD of this difference at each ABP was plotted. Each case was then divided into 5-min epochs for as long as 10 h, and the median value of the difference between NIBP and ABP in each epoch and its corresponding NIBP and ABP values were used for regression analysis. Mixed linear models were fitted to assess whether the differences in measurements were simply noise or a function of the ABP and time. The $R^2$ statistic for the linear mixed model was calculated to estimate the proportion of variation in responses explained by the two predictors after accounting for the covariance of the repeated measurements.[3] The concordance correlation coefficients between ABP and NIBP were also calculated.[4,5]

Patients with more than 20 records (5 min cumulative) of systolic ABP less than 90 mmHg were considered hypotensive, and those with systolic ABP more than 140 mmHg were considered hypertensive. The associations between monitoring strategy ([ABP] *vs.* [ABP+NIBP]) and subsequent use of drug and transfusion therapies and outcomes were tested in these two groups.

For each individual attending anesthesiologist (working with or without a resident or nurse anesthetist), the proportion of cases with hypotension in which NIBP was used was calculated, and the proportion of cases with hypotension in which transfusion was used was calculated. The correlation between these two proportions was tested to determine whether NIBP use was simply a marker of attending physicians who frequently (or infrequently) transfused blood, regardless of NIBP use. Subsequently, cases of attending physicians who almost always or almost never used NIBP and/or transfused blood were excluded so that each included attending could serve as his or her own control in the final analysis. A histogram of the logarithm of the odds of transfusion was plotted to see the effects of NIBP use on transfusion rates for each individual practitioner.

Because use of [ABP] *versus* [ABP+NIBP] was not a random assignment, a propensity score matched analysis was undertaken to assess the independent association of NIBP use on blood transfusion and adverse outcomes. First, a logistic regression model using patient and procedure factors, as well as attending anesthesiologist identity for each case, was created to predict the propensity toward using NIBP monitoring. Cases that were extreme outliers with regard to physiologic values (likely erroneous or artifactual) were excluded. Categories for continuous variables were created to allow for more flexible (*i.e.*, nonlinear logit) relationships with transfusion. Second, one-to-one matching using the replacement method was performed to search for the best matches on propensity scores between [ABP] and [ABP+NIBP] cases. The balance of the covariates between the resulting matched pairs was checked using *t* tests. Next, the weighted generalized estimating equations method with logit link was used to model the effect of NIBP use on the likelihood of transfusion and outcomes. This analysis assumed a practice pattern effect for each attending anesthesiologist.

All statistical inference was based on the two-sided test with significance level of 0.05. Software used for the analysis included SAS v9.2 (SAS Institute Inc., Cary, NC) and R Software v2.12.1.[6]

## Results

There were a total of 24,225 noncardiac cases using radial ABP. Among these, 15,310 (63%) had one or more concomitant NIBP measurements at an average frequency of 2.7 per hour. Graphical plots in figure 1 summarize the differences between NIBP and ABP over the observed range of ABP pressures. The graphical plots and the $\beta$-coefficients in the models (table 1) indicate that NIBP was likely to be higher than ABP at lower ABPs, and NIBP was likely to be lower than ABP at higher ABPs, with a crossover point between the two zones estimated at systolic ABP of 111 mmHg. Similar findings were found for diastolic and mean pressures. The relationships were not substantially different when the ABP and NIBP were on the ipsilateral *versus* contralateral sides, nor did the relationships change significantly over time (*i.e.*, earlier *vs.* later in the case).

There were 9,628 cases with hypotension, 37% of which had NIBP measured before the first transfusion or end of surgery, whichever came first. A total of 37% of the hypotensive patients were transfused with erythrocytes, and they

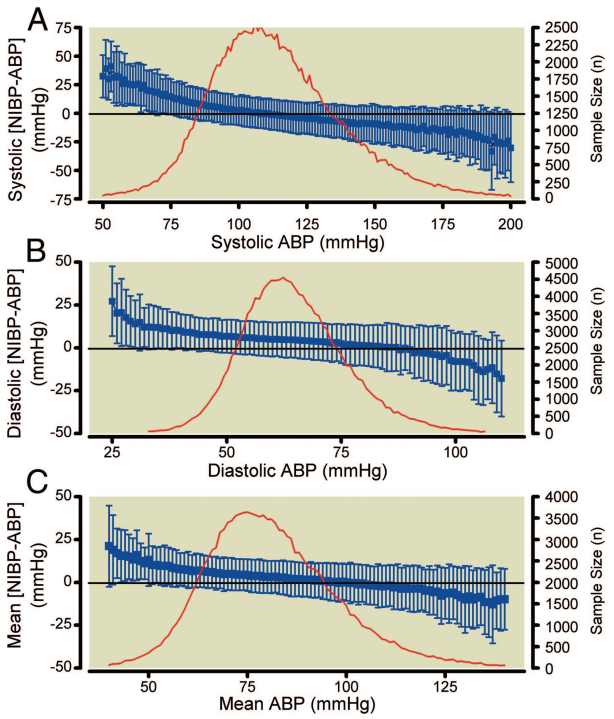


**Fig. 1.** Difference between oscillometric cuff and radial artery catheter measurements of blood pressure. Average difference (± SD) between simultaneous noninvasive (NIBP) and invasive radial artery (ABP) systolic (*A*), diastolic (*B*), and mean (*C*) blood pressure measurements in 24,225 adult patients during noncardiac surgery and anesthesia, as well as total sample size of data pairs for each ABP value (bell-shaped curve and right-side Y-axis).

received a median of two units. Transfusion occurred in 27% *versus* 43% of the [ABP+NIBP] *versus* [ABP] groups, respectively (chi-square $P < 0.01$). Vasopressor/inotrope infusions were used in 7% *versus* 18% of the [ABP+NIBP] *versus* [ABP] groups, respectively (chi-square $P < 0.01$). There were 16,587 patients with hypertension. Antihypertensive medications were administered to 12% *versus* 44% of the [ABP+NIBP] *versus* [ABP] groups, respectively (chi-square $P < 0.01$).

Analysis of practice patterns of 121 attending anesthesiologists for cases with hypotension and complete covariate data (table 2) showed no association between NIBP use and transfusion rates ($r = -0.08$, $P = 0.37$), suggesting that an individual's overall proclivity to transfuse blood was not closely related to the individual's overall tendency to use (or not use) NIBP. The effect of NIBP use could not be estimated for 14 attending physicians because of their high or low frequency of NIBP use and/or transfusion, so their cases (n = 487) were excluded from the analyses, resulting in a final sample size of 6,528 cases. There were 51 attending physicians with low case volume (*i.e.*, ≤15 cases), and they were combined and treated as a single practitioner for their cases (n = 349). The attending-specific effects of using NIBP on transfusion rates (in terms of the logarithm of the odds ratio) were normally distributed, and the average logarithm of the odds ratios across practitioners was −0.882 (SE = 0.086). This corresponds to an overall odds ratio of 0.41 (95% CI 0.35–0.49), suggesting that use of NIBP by individual attending physicians was associated with decreased odds of transfusion compared with their own cases without NIBP use.

Propensity score matching resulted in 2,725 case pairs that were adequately balanced for covariates and practitioners. The prediction model resulting from this analysis (table 3) demonstrated a significant decrease in the odds of transfusion (OR = 0.40, 95% CI for odds ratio 0.35–0.46) for the [ABP+NIBP] group compared with the [ABP] group, independent of other included factors. Other factors independently associated with decreased odds of transfusion were younger age, lower American Society of Anesthesiologists physical status classification, higher starting hematocrit, shorter procedure duration, less estimated blood loss, and less systolic blood pressure variability. There was no significant difference in in-hospital mortality (2.75% *vs.* 3.29%, $P = 0.15$) or abnormal troponin within 30 postoperative days (0.74% *vs.* 0.94%, $P = 0.36$) for the [ABP] *versus* [ABP+NIBP] groups, respectively.

## Discussion

Our data showed a significant difference between intraoperative blood pressures when NIBP was compared with ABP. NIBP was likely to be higher than ABP at lower pressures, and NIBP was likely to be lower than ABP at higher pressures. Our data also suggest that, in many cases, practitioners

**Table 1.** Distribution and Prediction Model of Blood Pressures Measured Simultaneously by Oscillometric Cuff and Radial Artery Catheter

| Pressure | NIBP Average (SD) mmHg | ABP Average (SD) mmHg | Concordance Correlation between NIBP and ABP | Average Difference* (SD) mmHg | β-Coefficient (SE) for Difference *vs.* ABP | Crossover† mmHg | $R^2$ |
|---|---|---|---|---|---|---|---|
| Systolic | 114 (22) | 115 (24) | 0.77 | −1 (16) | −0.32 (0.002) | 111 | 0.257 |
| Diastolic | 67 (14) | 62 (13) | 0.64 | 5 (11) | −0.29 (0.002) | 80 | 0.133 |
| Mean | 85 (16) | 81 (16) | 0.77 | 3 (10) | −0.24 (0.002) | 95 | 0.158 |

* Difference = NIBP minus ABP. † Estimated blood pressure below which NIBP became higher than ABP.
ABP = radial artery blood pressure; NIBP = noninvasive (oscillometric cuff) blood pressure; SE = standard error.

**Table 2.** Patient and Procedure Variables Grouped by Presence of Noninvasive Blood Pressure Measurements in Hypotensive Patients*

| Variable | [ABP+NIBP] (n = 2,828) Mean, Median, or % | [ABP+NIBP] (n = 2,828) SD, Range | [ABP] (n = 4,261) Mean, Median, or % | [ABP] (n = 4,261) SD, Range | *P* Value |
|---|---|---|---|---|---|
| Age (yr) | 56.8 | 15.7 | 60.3 | 15.4 | <0.01 |
| Body mass index (kg/m$^2$) | 26.7 | 6.1 | 27.0 | 6.5 | 0.09 |
| Starting hematocrit (%) | 38 | 5.8 | 36 | 6.4 | <0.01 |
| ASA physical status | — | — | — | — | <0.01 |
| 1 | 4.8% | — | 1.9% | — | — |
| 2 | 32.6% | — | 21.1% | — | — |
| 3 | 52.9% | — | 56.7% | — | — |
| 4 | 9.5% | — | 19.1% | — | — |
| 5 | 0.2% | — | 1.2% | — | — |
| Inpatient (yes) | 29.8% | — | 40.6% | — | <0.01 |
| A-line *in situ* on arrival to OR (yes) | 1.4% | — | 5.5% | — | <0.01 |
| A-line before anesthesia induction (yes) | 10.1% | — | 21.7% | — | <0.01 |
| Emergency case (yes) | 22.4% | — | 24.2% | — | 0.08 |
| Average systolic ABP (mmHg) | 106 | 10 | 112 | 12 | <0.01 |
| Procedure duration (h) | 4.33 | 0.25–14.7 | 4.03 | 0–19.4 | <0.01 |
| Estimated blood loss (ml) | 400 | 5–18,500 | 400 | 0–26,500 | <0.01 |
| Pretransfusion average SBP (mmHg) | 107 | 10 | 113 | 12 | <0.01 |
| Pretransfusion SBP SD (mmHg) | 16 | 4–57 | 18 | 2–63 | <0.01 |
| Erythrocyte transfusion (yes) | 29.1% | — | 47.2% | — | <0.01 |

* Patients with continuous radial ABP monitoring and systolic ABP <90 mmHg for 5 min or more during surgery, with or without one or more NIBP measurements to supplement ABP during procedure (and before transfusion, if any).

ABP = radial artery blood pressure; ASA = American Society of Anesthesiologists; NIBP = noninvasive (oscillometric cuff) blood pressure; OR = operating room; SBP = systolic blood pressure.

completely forego NIBP monitoring once ABP monitoring is available, even during episodes of apparent hypo- or hypertension. However, this practice was associated with an increased use of intraoperative blood transfusion, vasopressor or inotrope infusion, and antihypertensive medication administration.

We postulate that during periods of hypotension, when blood transfusion or vasopressor infusion may be considered, NIBP tends to be higher than ABP and reassures the clinician that such intervention may not be necessary. Similarly, during periods of hypertension, NIBP tends to be lower than ABP, making antihypertensive therapy seem less warranted. Thus, clinicians who do not measure NIBP to supplement ABP measurements may intervene more often for low and high ABP. Because blood transfusion, vasopressor or inotrope infusion, and antihypertensive therapy may all be associated with adverse outcomes[7–9] and NIBP monitoring is safe, inexpensive, and ubiquitous, NIBP measurement is recommended concomitant with ABP monitoring to help clinicians interpret ABP abnormalities and assist in clinical decision-making when ABP monitoring is used.

The low $R^2$ values in the models (table 1) indicate that most of the variation in the differences between NIBP and ABP cannot be reliably predicted by ABP alone. A more elaborate, multifactorial model might be more predictive, but such modeling is unnecessary considering that actual NIBP measurement (rather than prediction) can be made at almost any time without cost or risk. Our results highlight the importance of actually measuring NIBP, even when measurements from a radial artery catheter are available.

When a discrepancy between NIBP and ABP is seen, a practitioner may question which of the two is the "real" pressure upon which clinical decisions should be based. Because maintaining adequate blood pressure at vital organs is the usual goal of therapy, central pressure should probably be of more interest than peripheral pressure. Although many practitioners may assume that radial artery pressure (our most common site of ABP monitoring) is an accurate measure of more central pressures, many investigators have found that radial pressure is often lower than femoral or aortic pressures.[10–14] Thus, brachial pressure measured by NIBP cuff may be a better measure of central pressure when ABP indicates apparent hypotension.[15] Similarly, it has been reported that pulse pressure amplification occurs in peripheral vessels, and this may cause radial pressures (particularly systolic pressures) to be higher than more central pressures[16]; this may help explain why NIBP is lower than ABP in hypertensive patients. Still, some investigators have suggested that ABP and NIBP are interchangeable, particularly for mean pressures.[17,18]

One study similar to ours compared the two monitoring modalities during induced hypotension using volatile anesthetics in a small number of patients.[19] The authors reported the crossover between "overestimation" and "underestimation" of ABP by NIBP at approximately 80 mmHg, which is lower than the crossover seen in our analysis. We believe that what we have presented here is the largest sample size com-

**Table 3.** Propensity Score Matched Model for Prediction of Blood Transfusion in Hypotensive* Patients

| Factor | Values | Estimate | Standard Error | Odds Ratio | 95% CI | *P* Value |
|---|---|---|---|---|---|---|
| [NIBP+ABP] | — | −0.91 | 0.07 | 0.40 | 0.35–0.46 | <0.001 |
| Age (*vs.* >80 yr) | ≤20 | −0.95 | 0.30 | 0.39 | 0.22–0.69 | 0.001 |
| | 21–40 | −1.57 | 0.17 | 0.21 | 0.15–0.29 | <0.001 |
| | 41–60 | −1.02 | 0.14 | 0.36 | 0.28–0.47 | <0.001 |
| | 61–80 | −0.47 | 0.13 | 0.62 | 0.48–0.81 | <0.001 |
| Emergency | — | 0.27 | 0.08 | 1.31 | 1.13–1.54 | 0.001 |
| Inpatient status | — | 0.97 | 0.08 | 2.63 | 2.25–3.07 | <0.001 |
| ASA physical status (*vs.* 5) | 1–2 | −2.94 | 0.74 | 0.05 | 0.01–0.22 | <0.001 |
| | 3–4 | −2.26 | 0.73 | 0.10 | 0.02–0.44 | 0.002 |
| Starting hematocrit (*vs.* >40) | ≤20 | 3.35 | 1.02 | 28.50 | 3.83–211.9 | 0.001 |
| | 21–30 | 2.51 | 0.13 | 12.35 | 9.52–16.0 | <0.001 |
| | 31–40 | 1.25 | 0.08 | 3.51 | 2.99–4.11 | <0.001 |
| A-line *in situ* | — | −0.12 | 0.25 | 0.89 | 0.54–1.46 | 0.644 |
| Preinduction A-line | — | 0.01 | 0.11 | 1.01 | 0.82–1.26 | 0.894 |
| Estimated blood loss (*vs.* >1,000 ml) | ≤250 | −4.68 | 0.15 | 0.01 | 0.01–0.01 | <0.001 |
| | 251–500 | −3.31 | 0.13 | 0.04 | 0.03–0.05 | <0.001 |
| | 501–750 | −2.14 | 0.15 | 0.12 | 0.09–0.16 | <0.001 |
| | 751–1,000 | −1.24 | 0.15 | 0.29 | 0.22–0.39 | <0.001 |
| Procedure duration (*vs.* >6 h) | ≤2 | −2.08 | 0.15 | 0.12 | 0.09–0.17 | <0.001 |
| | 2–3 | −1.46 | 0.11 | 0.23 | 0.18–0.29 | <0.001 |
| | 3–4 | −1.07 | 0.10 | 0.34 | 0.28–0.42 | <0.001 |
| | 4–5 | −1.10 | 0.11 | 0.33 | 0.27–0.41 | <0.001 |
| | 5–6 | −0.53 | 0.11 | 0.59 | 0.47–0.73 | <0.001 |
| Average pretransfusion systolic ABP (*vs.* >150 mmHg) | ≤100 | −0.56 | 0.66 | 0.57 | 0.16–2.08 | 0.396 |
| | 101–125 | −1.23 | 0.65 | 0.29 | 0.08–1.06 | 0.061 |
| | 126–150 | −0.78 | 0.67 | 0.46 | 0.12–1.69 | 0.241 |
| Coefficient of variation† of systolic ABP (*vs.* >30) | <10 | −1.03 | 0.33 | 0.36 | 0.19–0.69 | 0.002 |
| | 11–20 | −0.52 | 0.31 | 0.59 | 0.33–1.08 | 0.088 |
| | 20–30 | 0.25 | 0.31 | 1.29 | 0.70–2.37 | 0.417 |

* Systolic ABP less than 90 mmHg for 5 min or more during surgery. † Coefficient of variation = 100 * SD/mean (a measurement of spread of ABP data for each subject).

ABP = radial artery blood pressure; [ABP+NIBP] = one or more NIBP measurements during procedure (and before transfusion, if any) concomitant with radial ABP monitoring; ASA = American Society of Anesthesiologists; NIBP = noninvasive (oscillometric cuff) blood pressure.

parison of NIBP and radial ABP in an adult population undergoing anesthesia and noncardiac surgery and the first demonstration of an association between choice of monitoring strategy and subsequent interventions.

This study was limited by its retrospective design and source of data from a single center. However, the large sample size and mix of procedures and practitioners help make the data widely applicable to other centers. Various factors not included in our analysis likely contributed to decisions to transfuse blood, but we have no reason to believe that such factors were unevenly distributed among cases with regard to NIBP use. Our analysis of practice patterns and propensity matching that included individual practitioners as covariates allowed us to consider issues such as the possibility that practitioners who use NIBP to supplement ABP might have been a group that also avoids transfusion and other interventions. It also helped demonstrate that most practitioners are less likely to transfuse blood when NIBP is used to supplement ABP compared with their own cases in which only ABP is used. Although our analysis of outcomes suggested that the use of NIBP was not associated with worse outcomes, there remains the possibility that this monitoring strategy (and associated decreased odds of intervention) could lead to negative outcomes not captured in our studies (*e.g.*, stroke) or in certain situations not specifically addressed in our investigation.

Although the size of the NIBP cuff is not documented in our AIMS, our experience is that most NIBP cuffs are appropriately sized and placed over the brachial artery, and our data overall represent real-world use of NIBP. Our data also do not reflect individual failed NIBP measurements such as may occur with severe hypotension, but this is not believed to have affected our results. Our data set lacked sufficient numbers of axillary or femoral catheters to study the use of those alternate sites that may better reflect central pressure.

In summary, we found statistically and clinically significant differences between blood pressures measured invasively and non-invasively, with NIBP generally higher than ABP when ABP was low, and lower when ABP was high. The use of NIBP measurement to supplement ABP measurements was associated with decreased use of blood transfusions, vasopressor or inotrope infusions, and antihypertensive medications compared with use of ABP measurement alone.

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